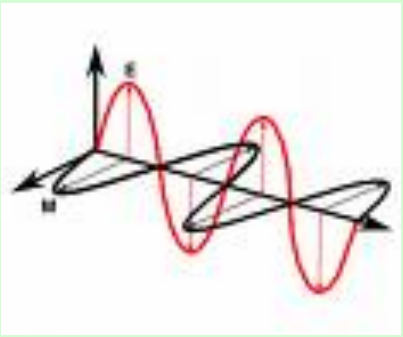


Using Polarimetry to test strong gravity and extreme physics

Giorgio Matt

(Dip. Fisica, Università Roma Tre)

X-ray polarimetry may:

Probe strong gravity effects around Black Holes

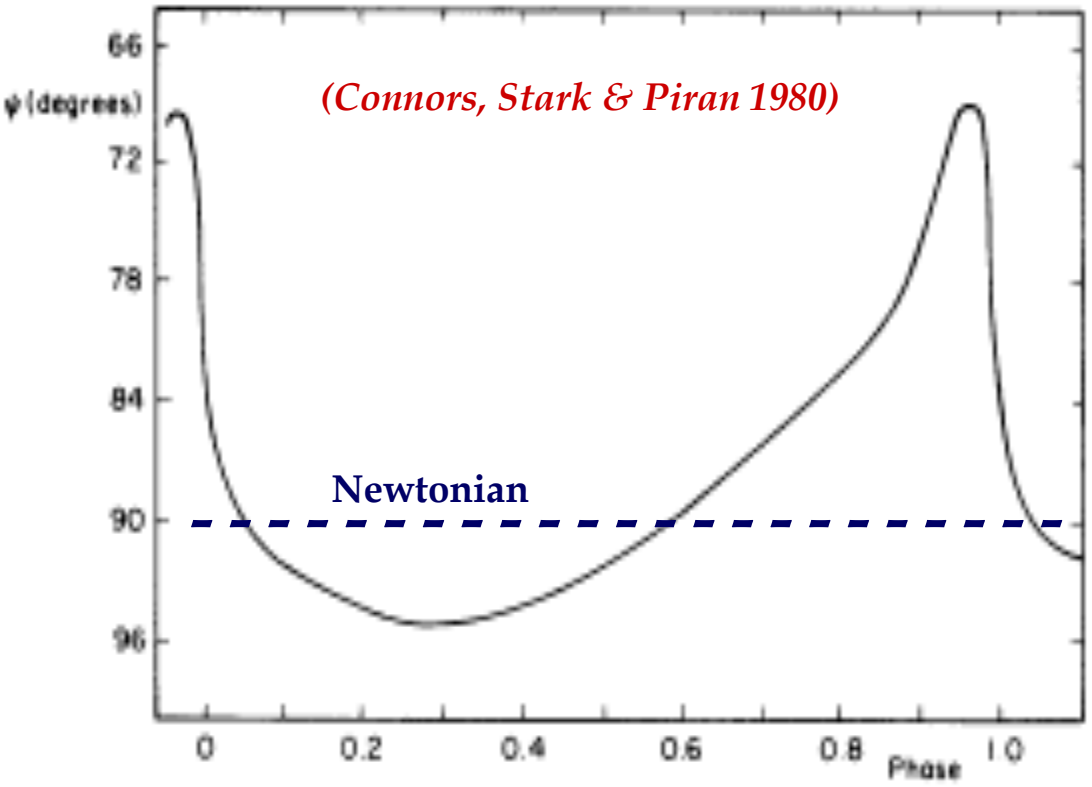
Study strong and extreme magnetic fields in compact sources

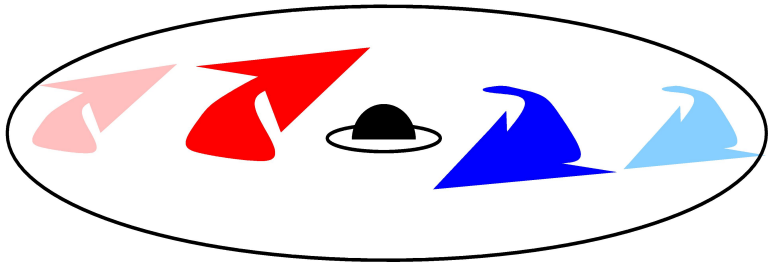
Perform tests of Fundamental Physics (QG, Axions, …)

Strong gravity effects on polarization

General and Special Relativity effects around a compact object (here-in-after collectively indicated as "strong gravity effects") significantly modifies the polarization properties of the radiation.

In particular, the Polarization Angle (PA) as seen at infinity is rotated due to aberration (SR) and light bending (GR) effects (e.g. Connors & Stark 1977; Pineault 1977). The rotation is larger for smaller radii and higher inclination angles



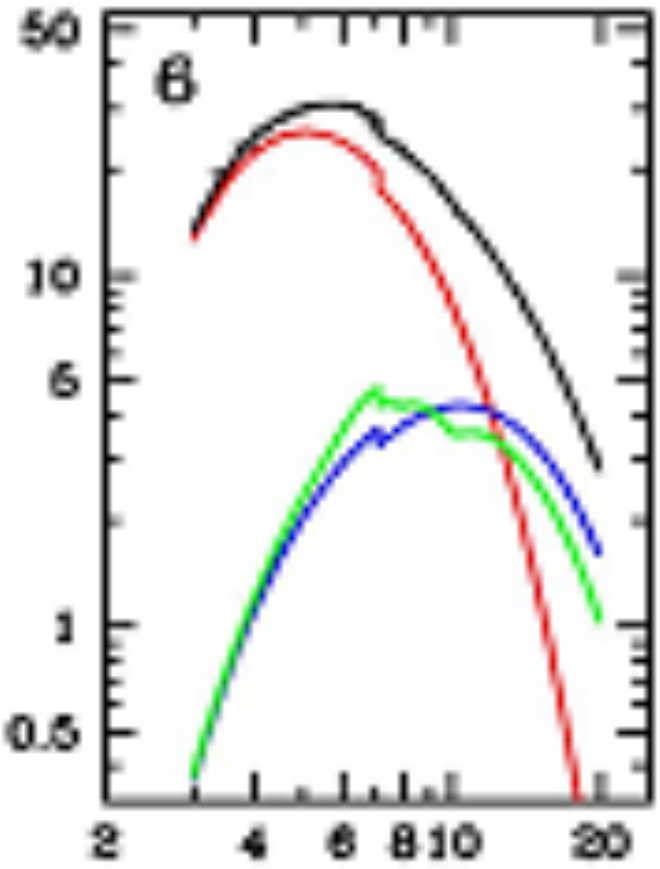


Orbiting spot with:
a=0.998; R=11.1 Rg
i=75.5 deg

(Phase=0 when the spot is behind the BH).

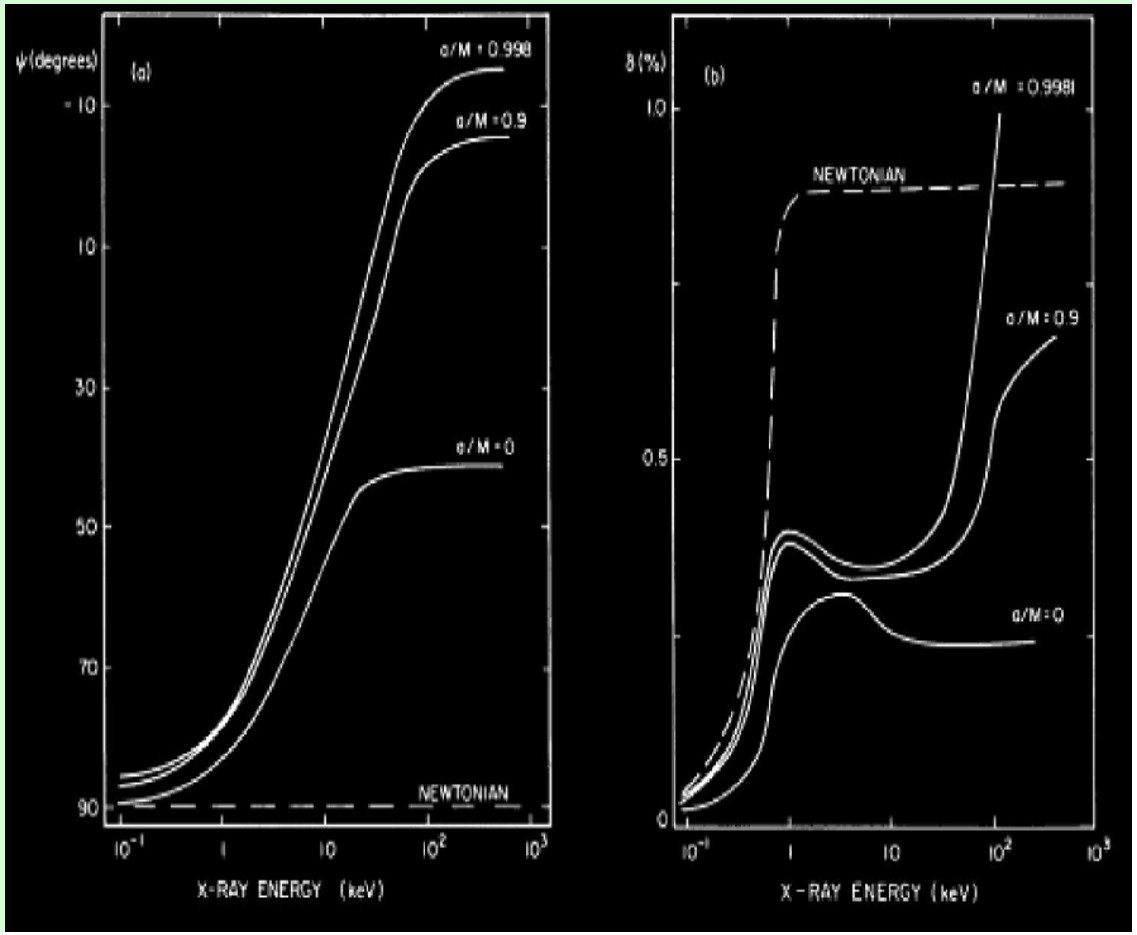
The PA of the net (i.e. phase-averaged) radiation is also rotated!

Galactic BH binaries in high state

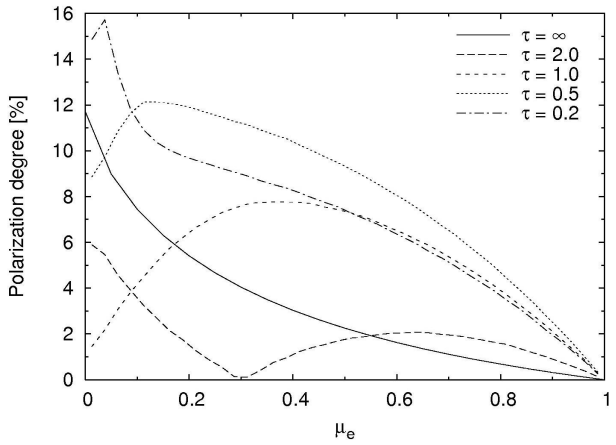


GRS 1915+105
(Done & Gierlinski 2004)

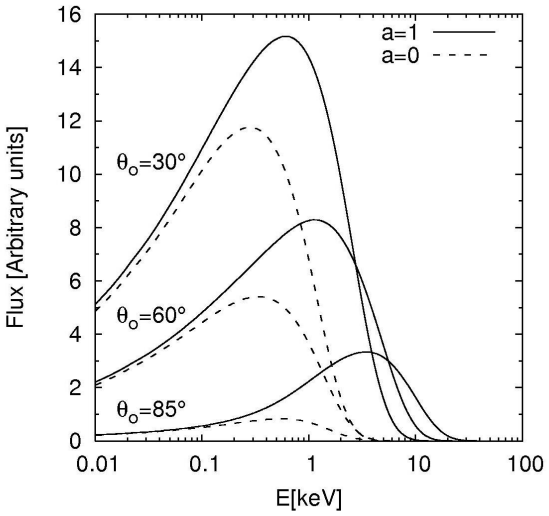
X-ray emission in Galactic BH binaries in soft states is dominated by disc thermal emission, with *T decreasing with radius.*
A rotation of the polarization angle with energy is therefore expected.



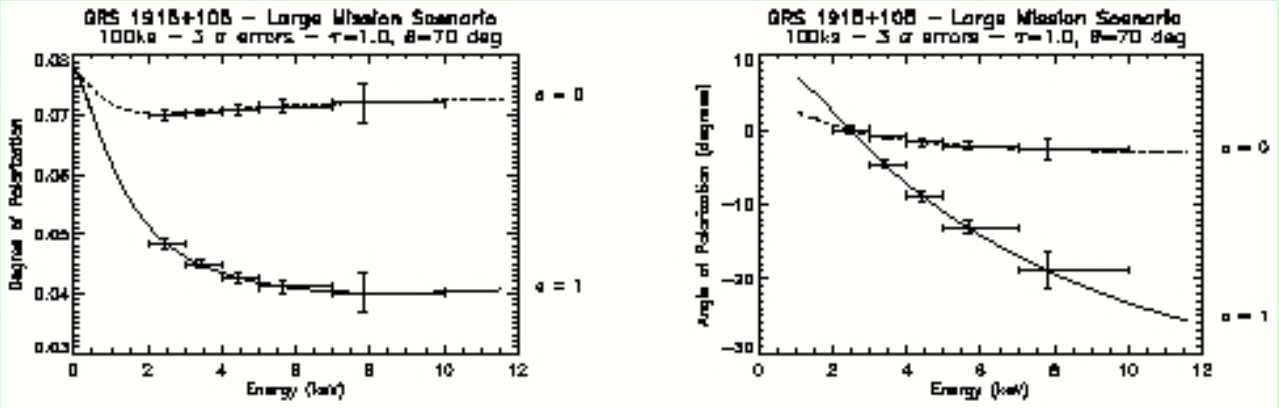
Connors & Stark (1977)



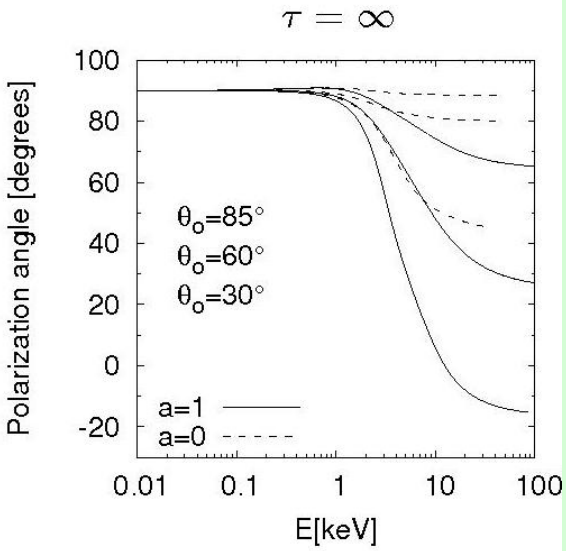
We (Dovciak et al. 2008) revisited and refined these calculations (see also Li et al. 2008, Schnittman & Krolik 2009).



Strongly dependent on the spin of the BH !!



Detectability of the effect with IXO



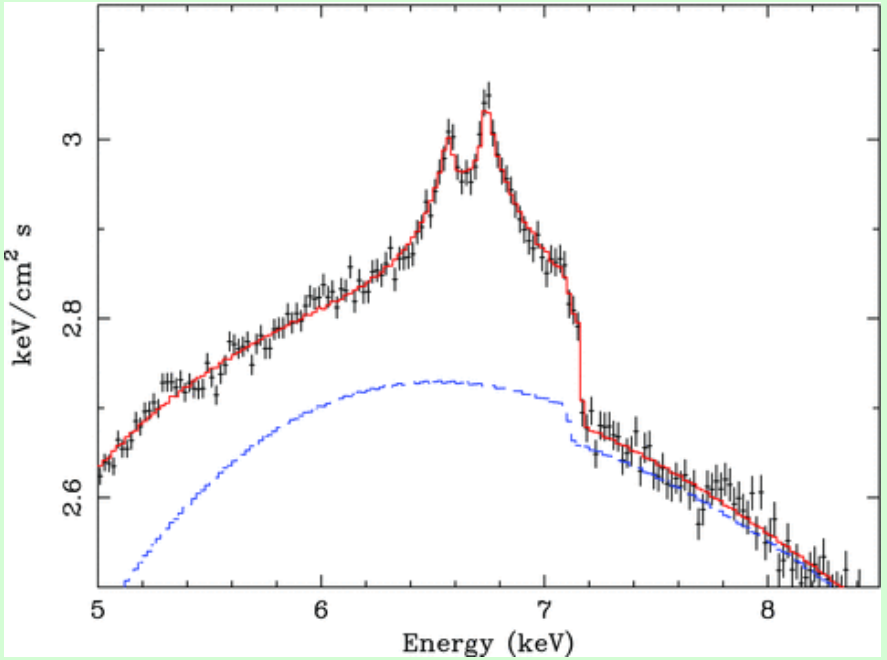
Broad iron Kα lines in XRB. Relativistic disc or Comptonization?

Broad iron Kα lines are often observed in XRB (both BH and NS systems). Relativistic disc or Comptonization?

(Not always is the line profile so clear as in 4U 1705-44)

Polarimetry may tell !!

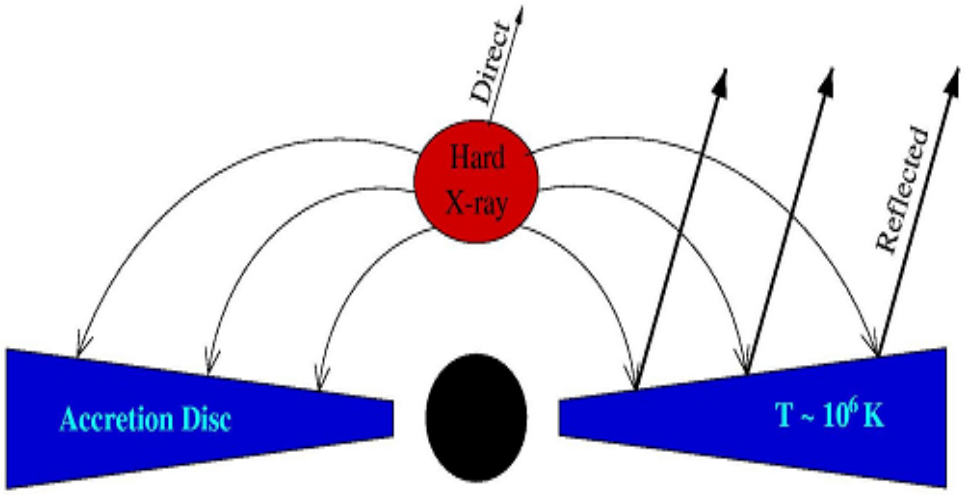
(Tamborra, Matt & Stella, work in progress)



4U1705-44, di Salvo et al. (2009)

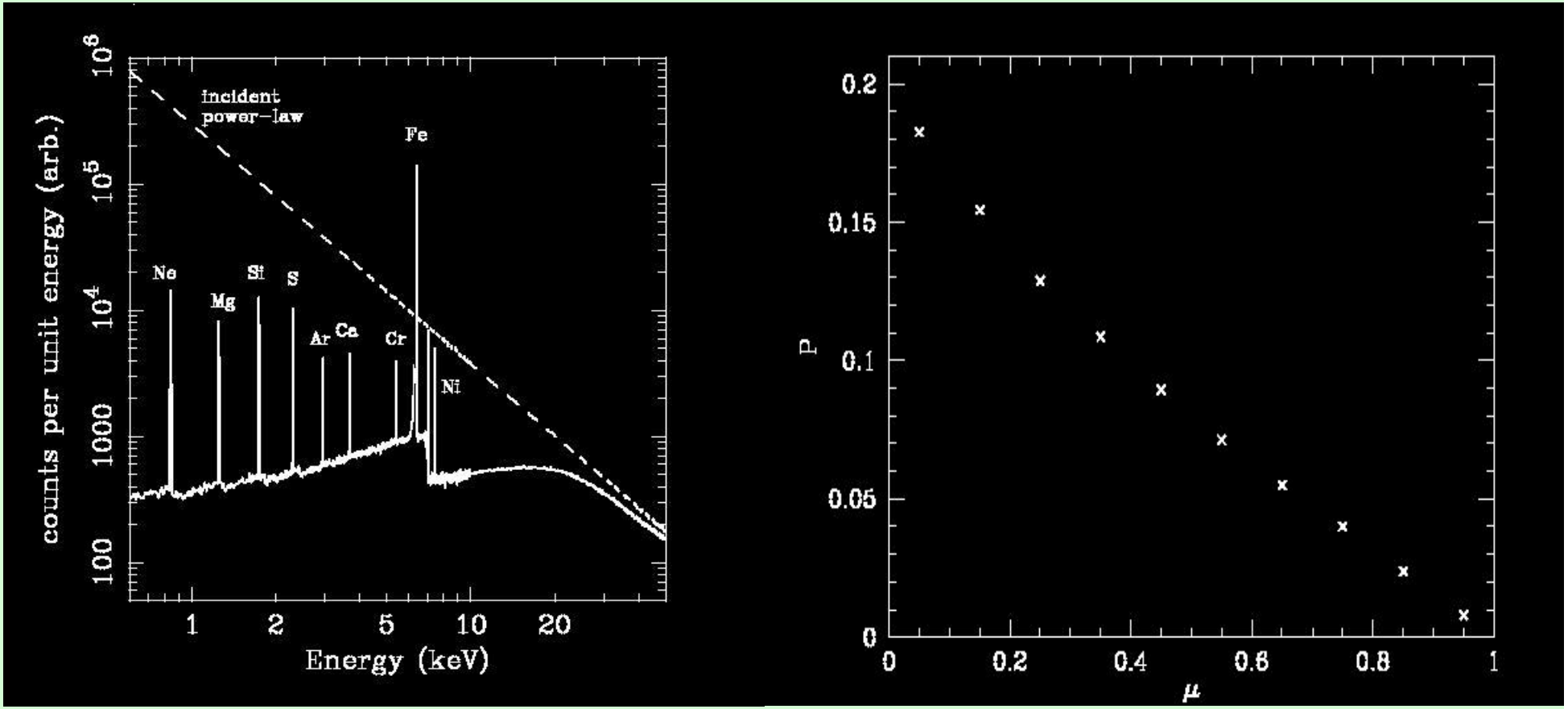
Active Galactic Nuclei (radio-quiet)

In Active Galactic Nuclei (and GBH in hard state) the primary X-ray emission is due to Inverse Compton by electrons in a hot Corona of the UV/Soft X-ray disc photons. It is likely to be significantly polarized (e.g. Haardt & Matt 1993, Poutanen & Vilhu 1993), because the system is unlikely to have a spherical symmetry.



Part of the primary emission illuminates the disc and is reflected (and polarized) via Compton Scattering

Polarization of reflected flux

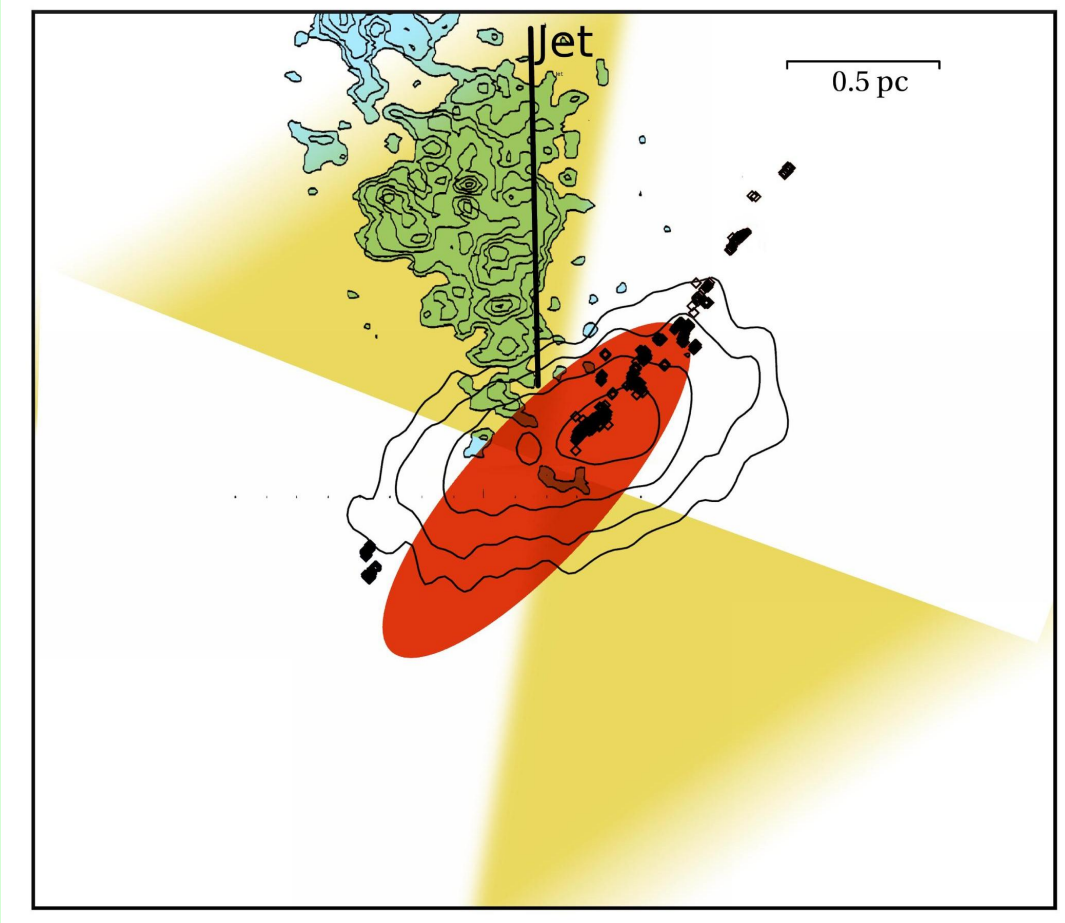


Polarization of reflected (continuum) radiation is large. For instance, it is up to 20% (Matt et al. 1989) assuming isotropic illumination, a plane-parallel reflecting slab and unpolarized illuminating radiation.
The exact values depend on the actual geometry of the system
(→ Compton-Thick, reflection-dominated AGN)

A diversion: the orientation of the Torus

Geometry of the torus:

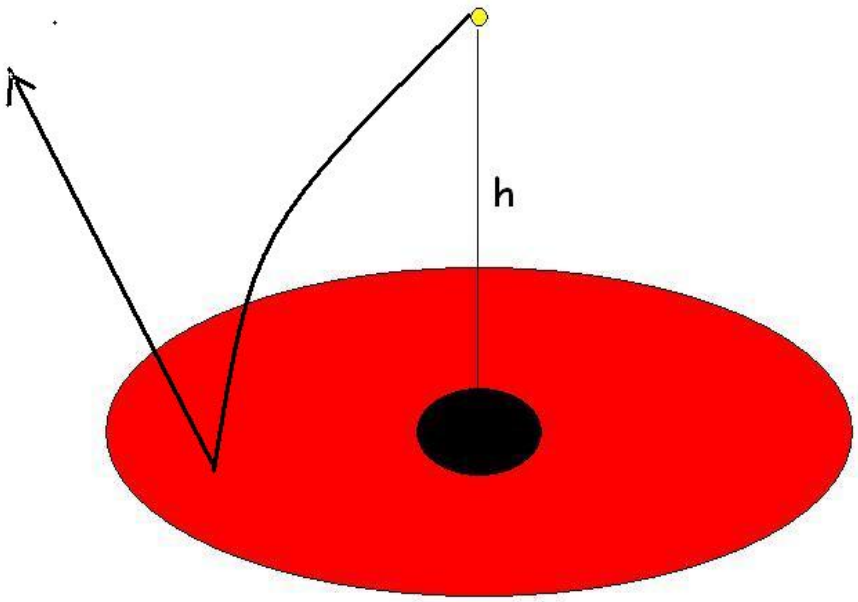
the polarization angle will give us the orientation of the torus, to be compared with IR results, and with the ionization cones (Goosmann & Matt 2010)

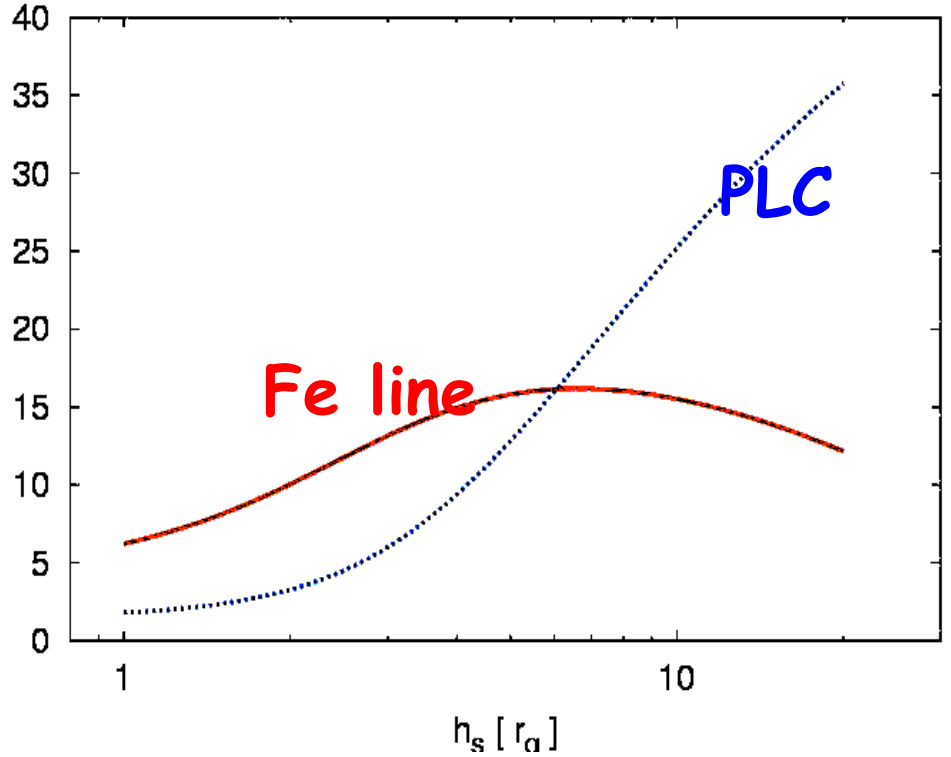


Raban et al. 2009

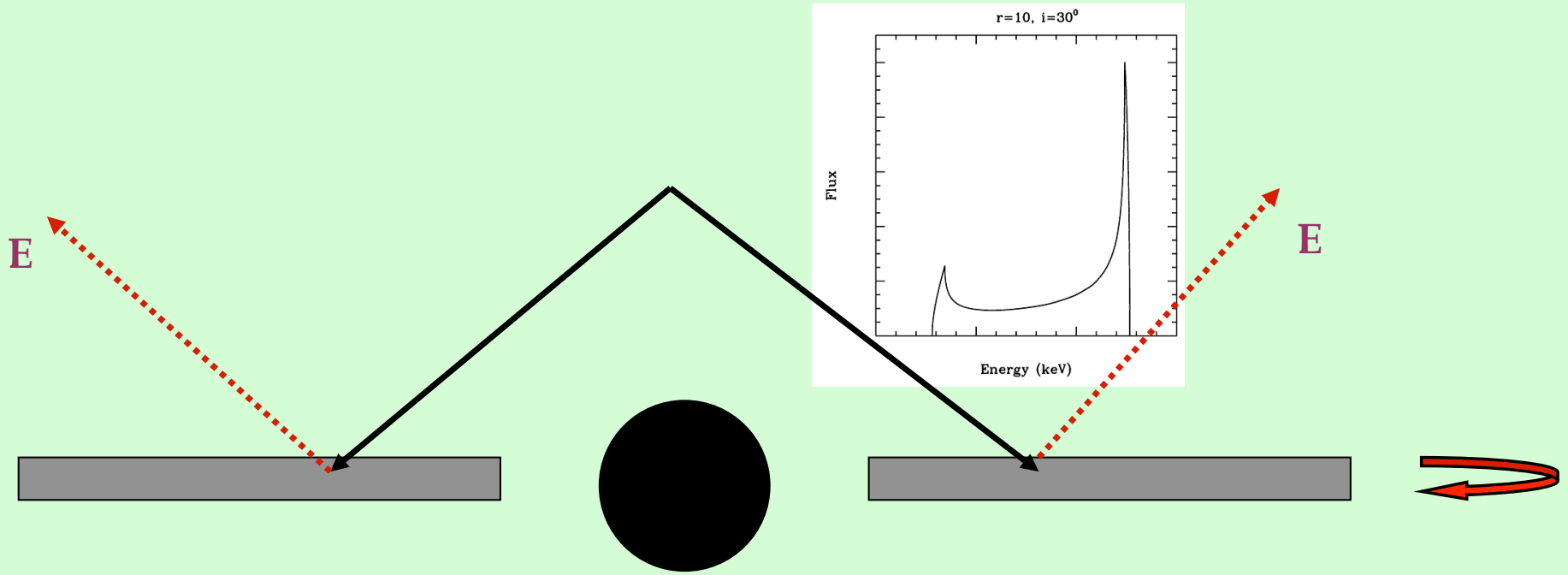
GR effects: light bending model

Variations of *h* have been suggested to be the cause of the puzzling temporal behaviour of the iron line in MCG-6-30-15 (Miniutti et al. 2003), where the line flux varies much less than the primary power law flux. This situation is expected aborted jet models for the corona (e.g. Ghisellini et al. 2004).



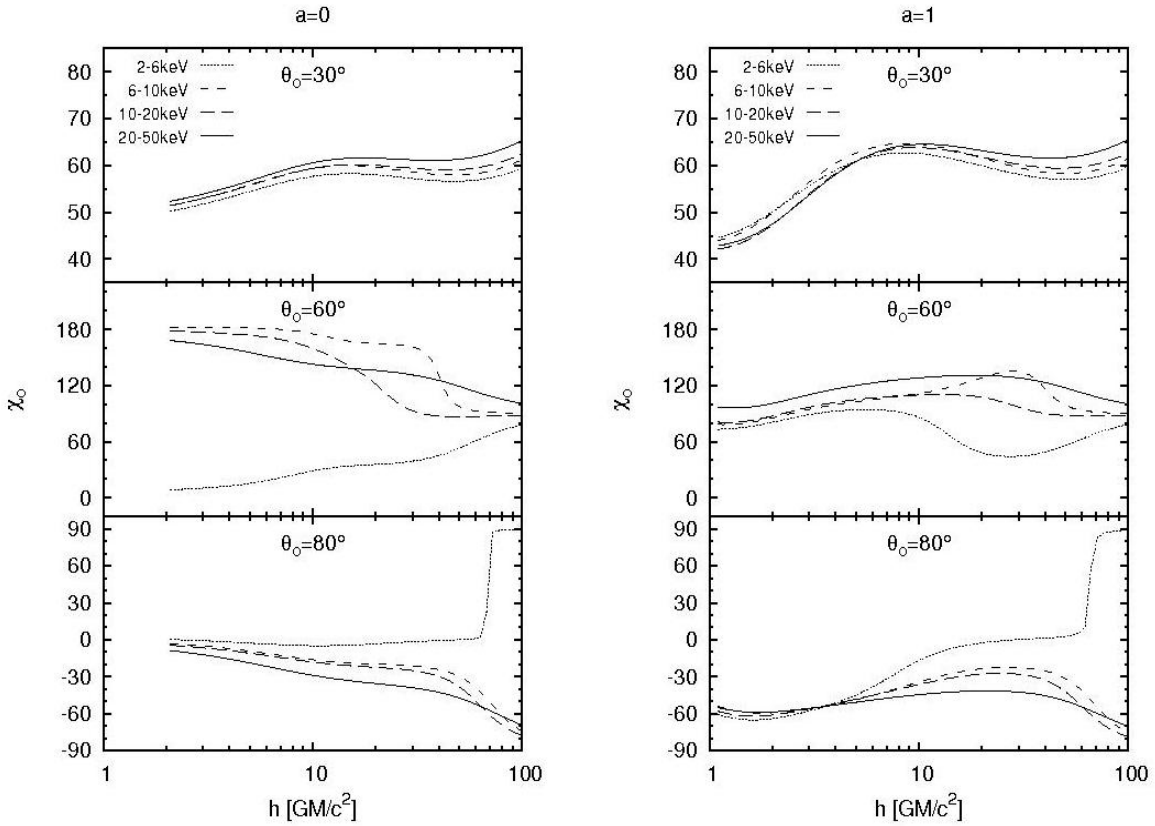


Reflection in Relativistic discs



Breaking of the symmetry due to SR (Doppler boosting) adds to the effects already mentioned, causing the rotation of the PA with respect to the Newtonian case. Changes in the illumination properties (e.g. in the height of the lamp-post) will cause changes in the total PA, which is therefore likely to be time dependent (relevant for AGN, timescales too short for GBH).

Polarization of reflected radiation



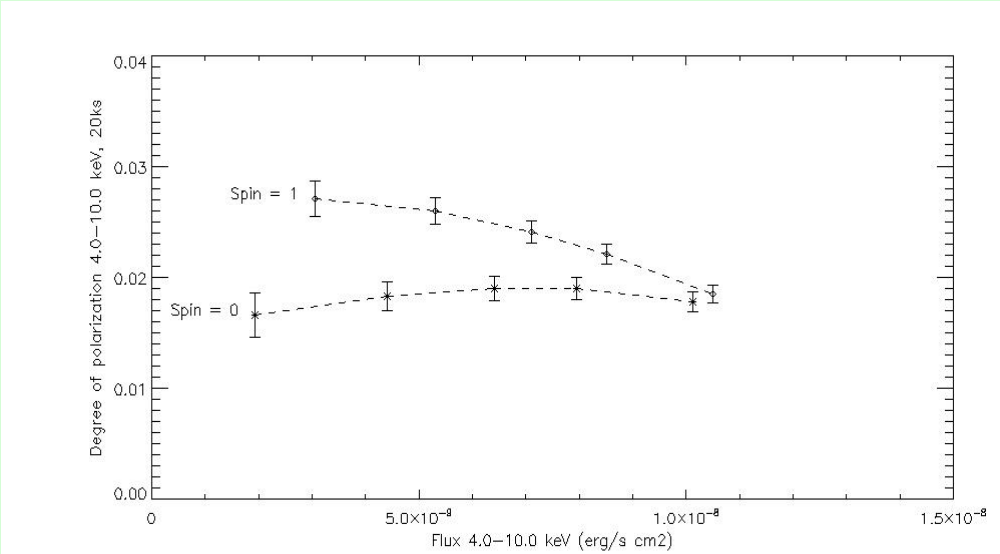
The polarization degree and angle depend on both *h* and the incl. angle (the latter may be estimated from the line profile; for MCG-6-30-15 is about 30 degrees, Tanaka et al. 1995)

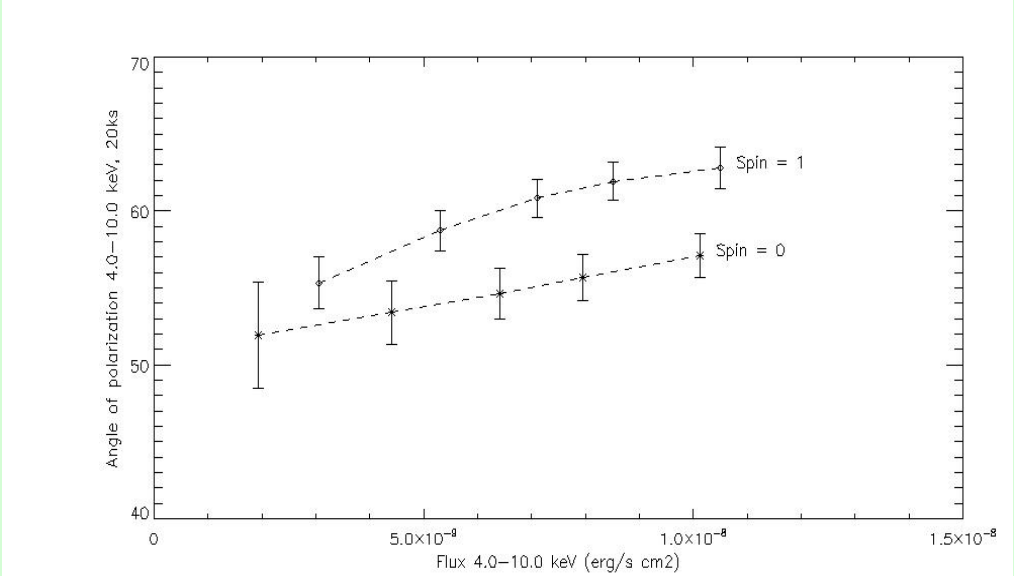
Variation of h with time/flux implies a time/flux variation of the degree and angle of polarization

Dovciak et al. 2004, and in prep. -
See also the poster by Dovciak et al.

Testing light bending model with polarimetry

Testing the light bending model in AGN is challenging, as dilution by the primary emission (assumed unpolarized – work is in progress to assess this point) makes the effect small.



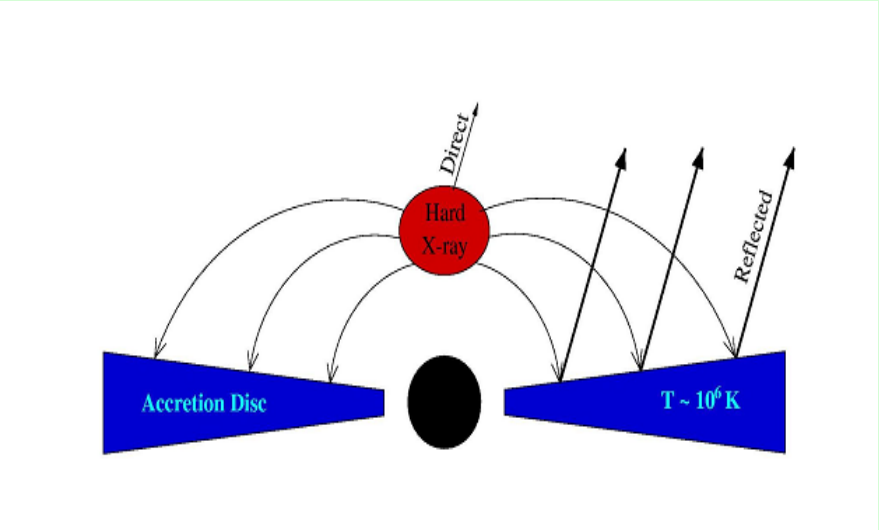


Fortunately, the LB model may work on GBH as well.

J1650-500
(Courtesy of Fabio Muleri)

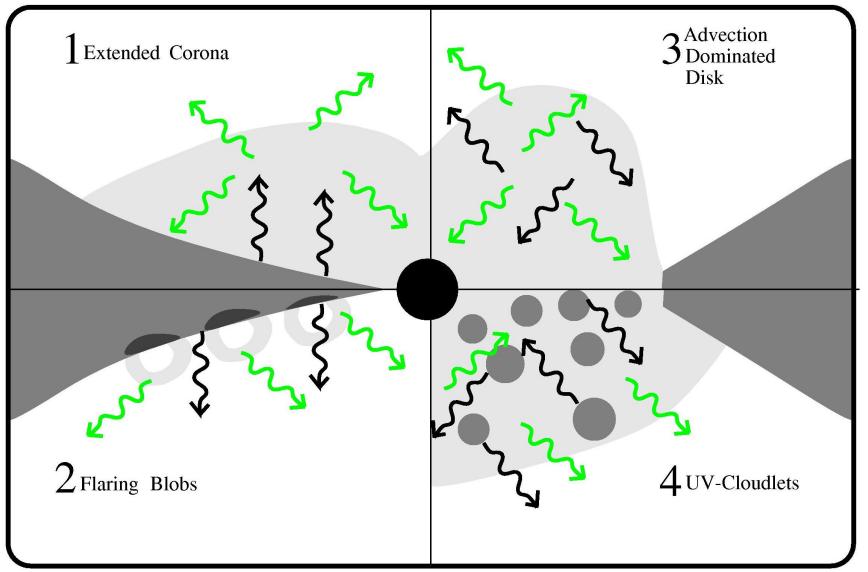
Primary emission from the hot corona

The geometry of the hot corona is unknown. Emission is expected to be polarized if the corona OR the radiation field are not spherical



Polarimetry will help understanding the geometry of the emitting region

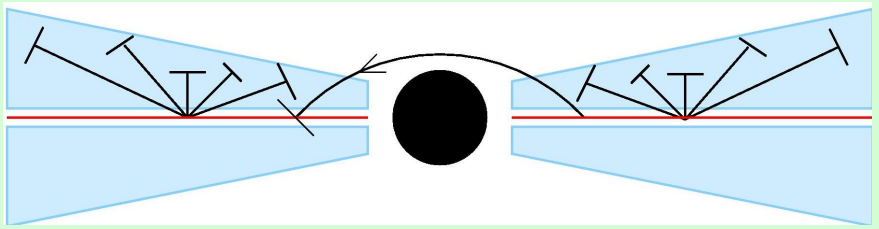
NB: in ADAF models, no significant polarization is expected (LLAGN/GBH in quiescence should be unpolarized)

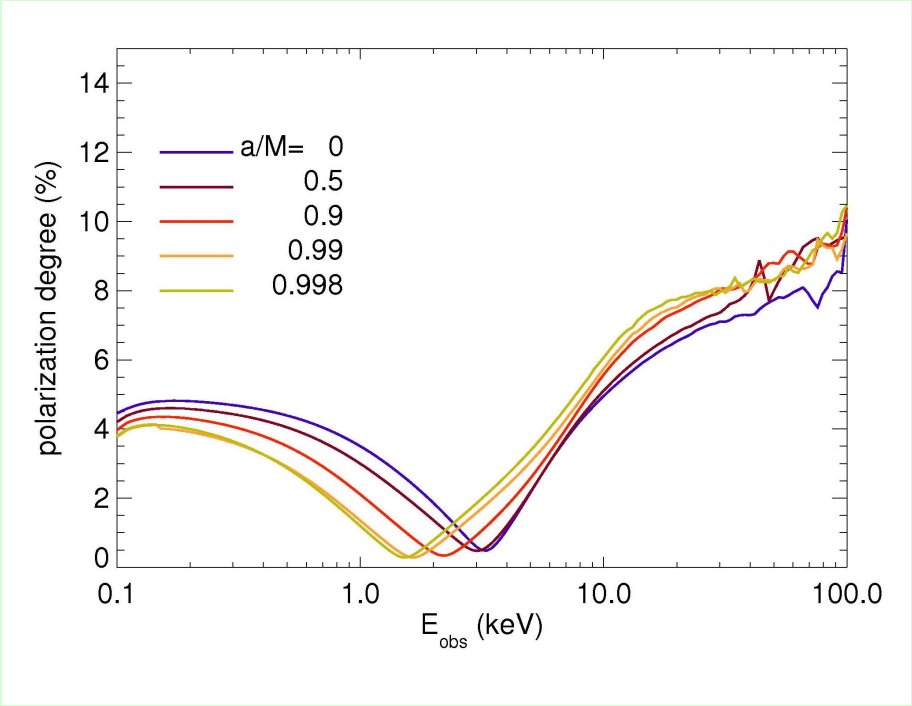


Haardt (1997)

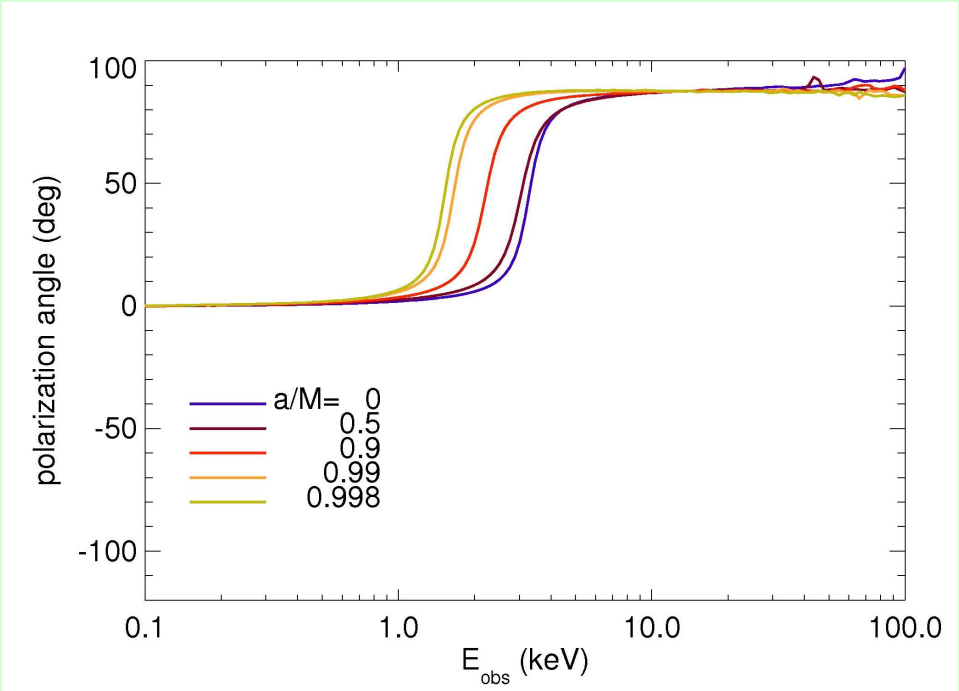
Primary emission from the hot corona

Coronal emission is significantly polarized





Polarization degree and angle depend on spin



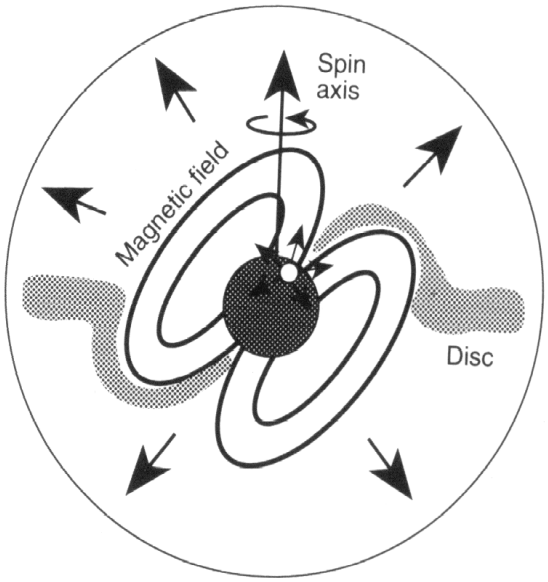
Schnittman & Krolik (2010)

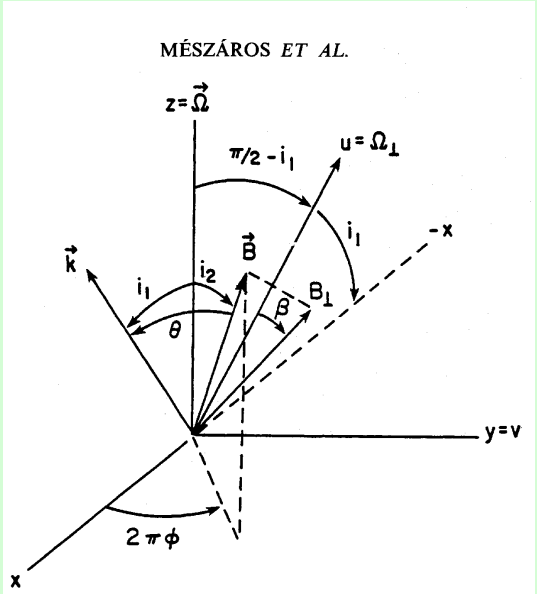
Very strong Magnetic Fields: X-ray Pulsars

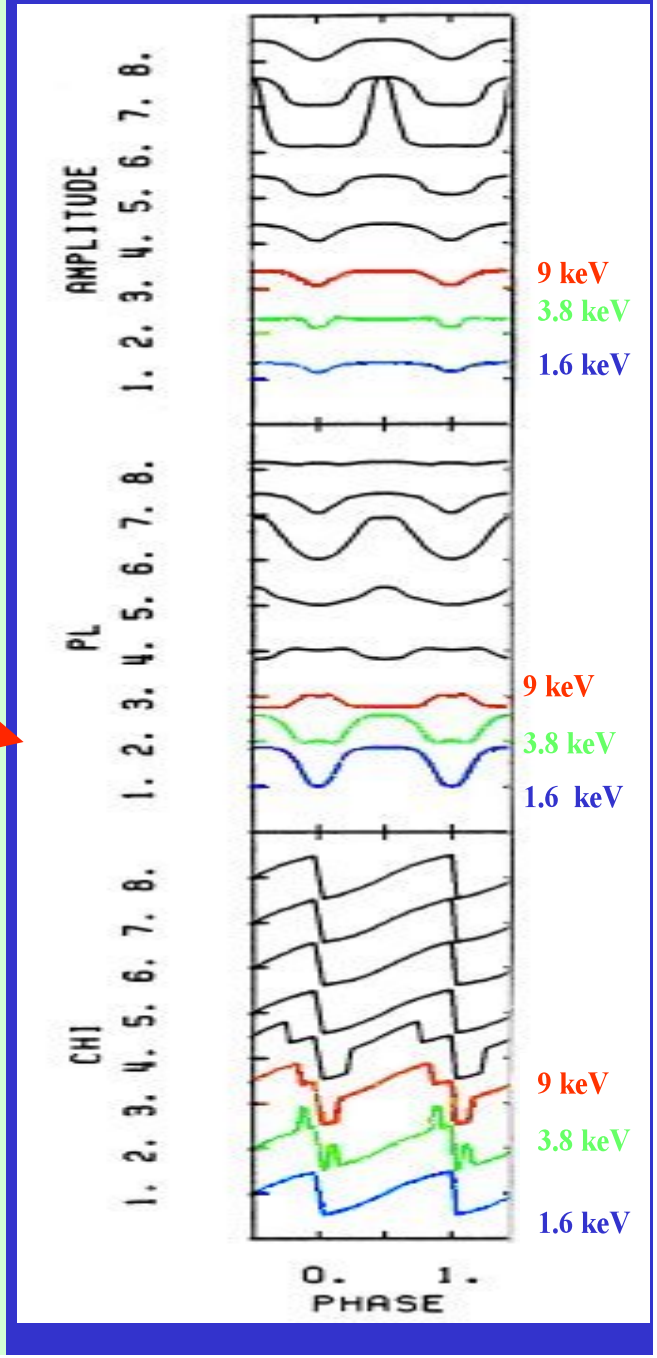
Polarized by:

- Emission process: cyclotron
- Scattering on highly magnetized plasma: $\sigma_{\parallel} \neq \sigma_{\perp}$

Polarization is modulated and the swing of the polarization angle with phase directly measures the orientation of the rotation axis on the sky and the inclination of the magnetic field: in the figure the 45° case is illustrated (from Meszaros et al. 1988)







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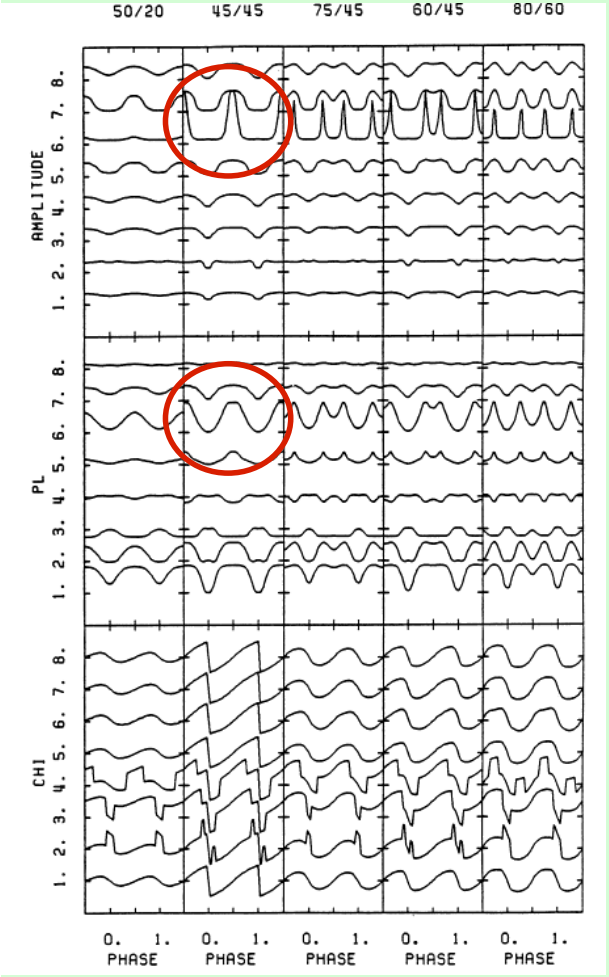
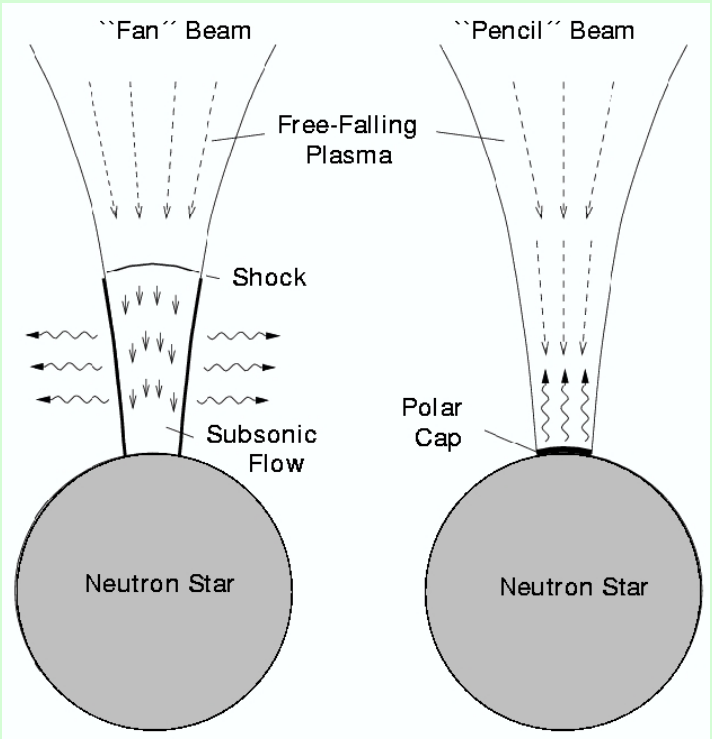
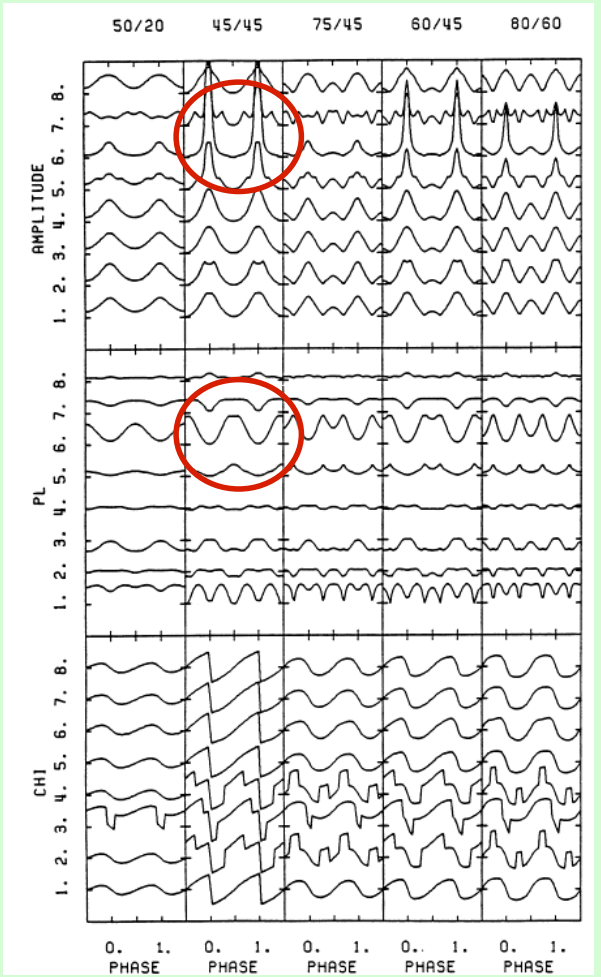
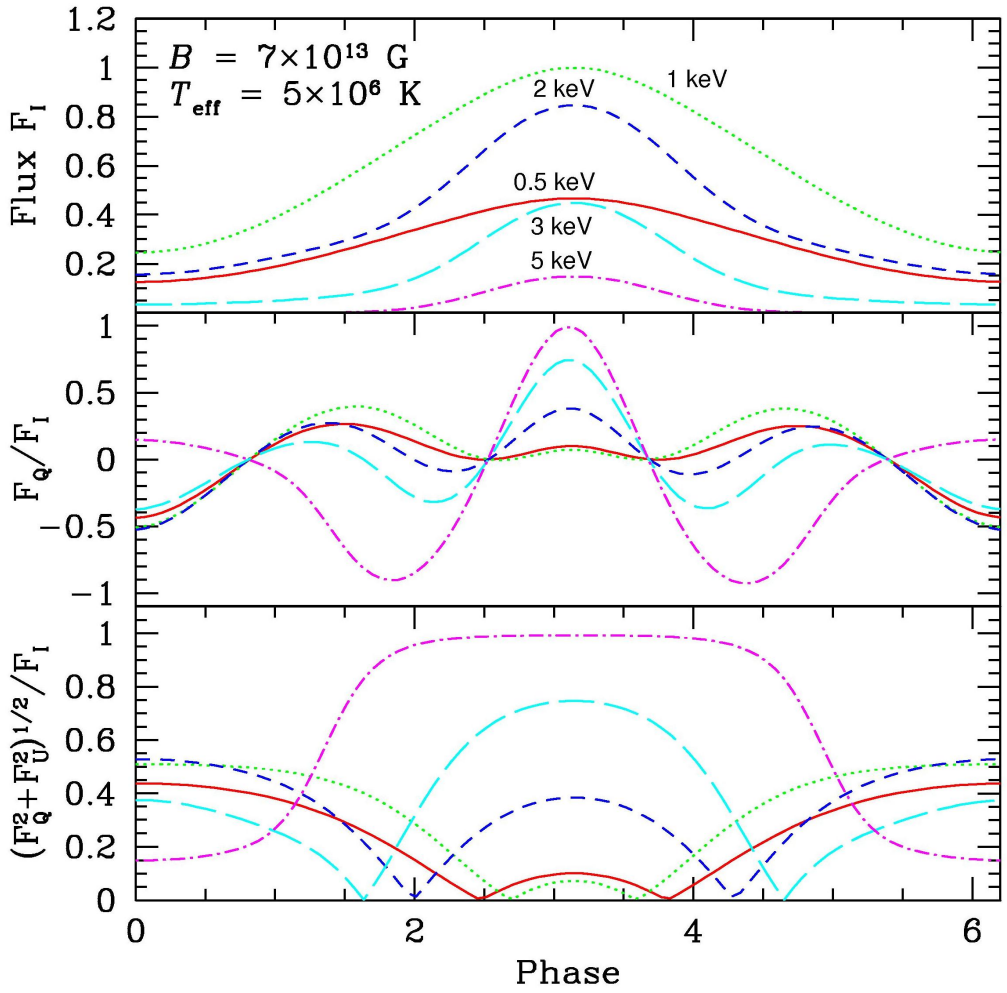






Meszaros et al. 1988

Extreme Magnetic Fields: magnetars

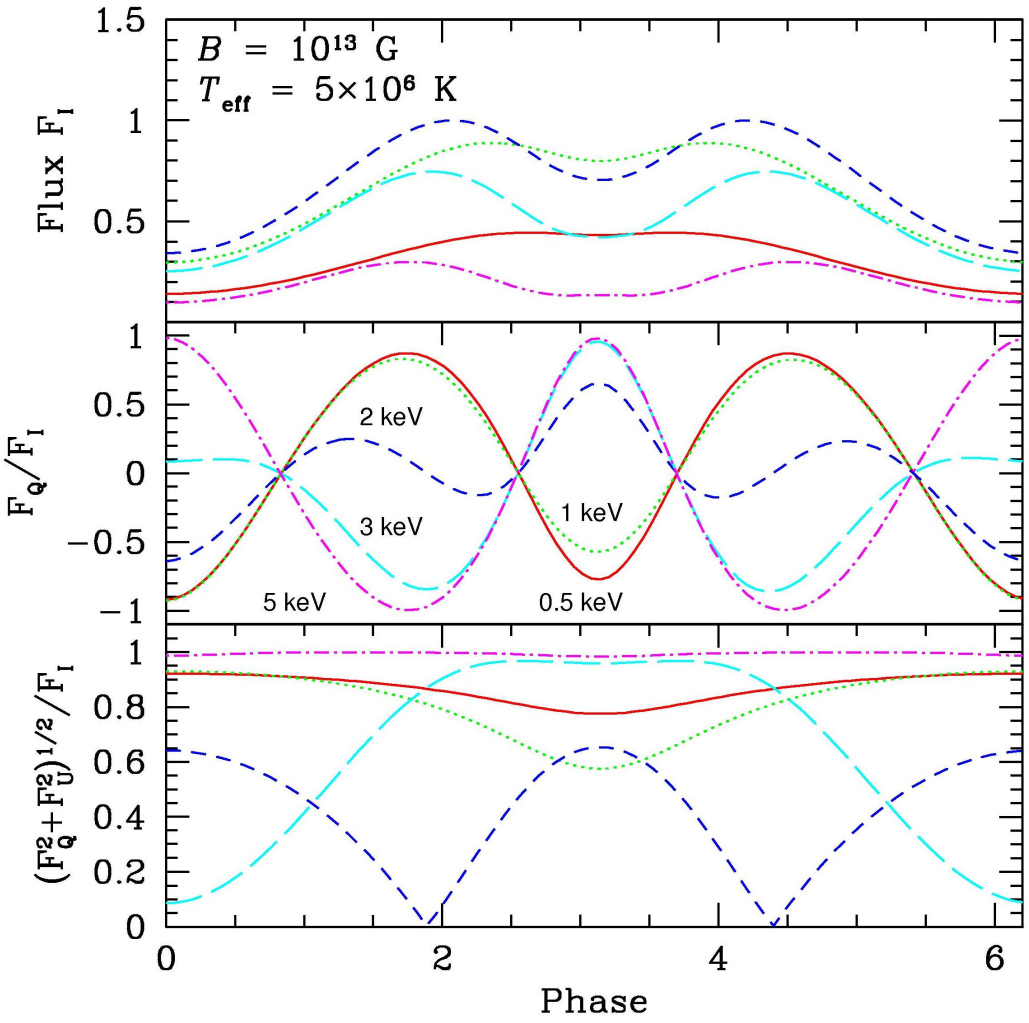


van Adelsberg & Lai 2006

Soft Gamma Repeaters and Anomalous X-ray Pulsars are interpreted in the frame of the Magnetar Theory (Thompson & Duncan 1993): neutron stars with extreme magnetic fields.

For $B \geq 7\times10^{13}$ G strong-field QED (vacuum polarization) becomes important, significantly changing the dependence on the phase *and the energy* of the polarization, providing a measurement of B, a test of the magnetar paradigm and a probe of strong-field QED

Extreme Magnetic Fields: magnetars



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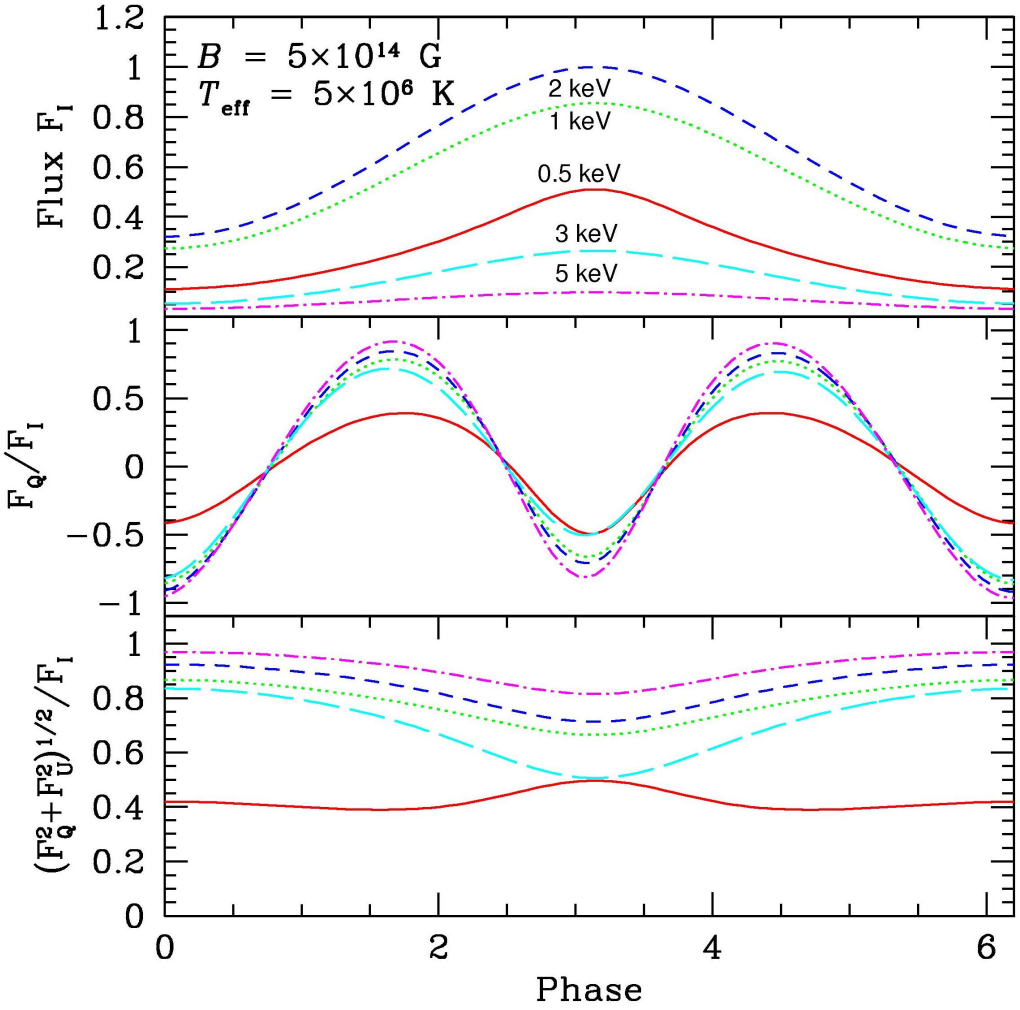

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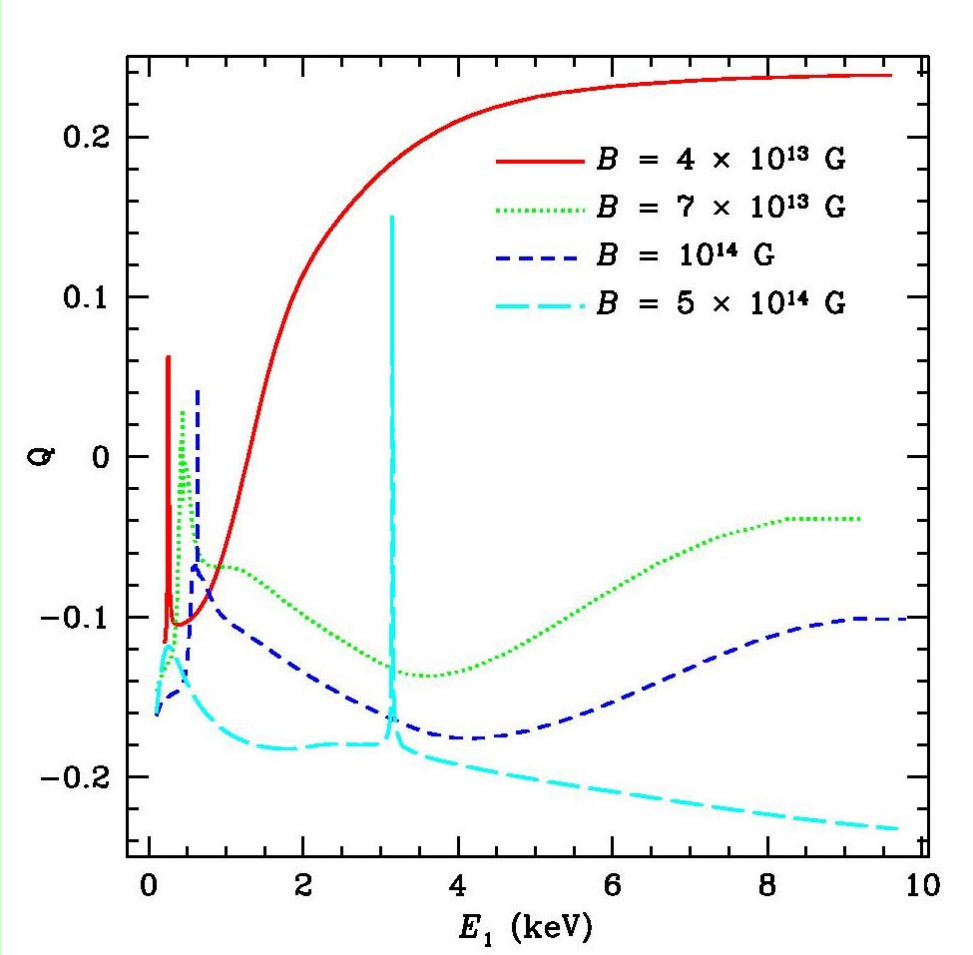

van Adelsberg & Perna 2009

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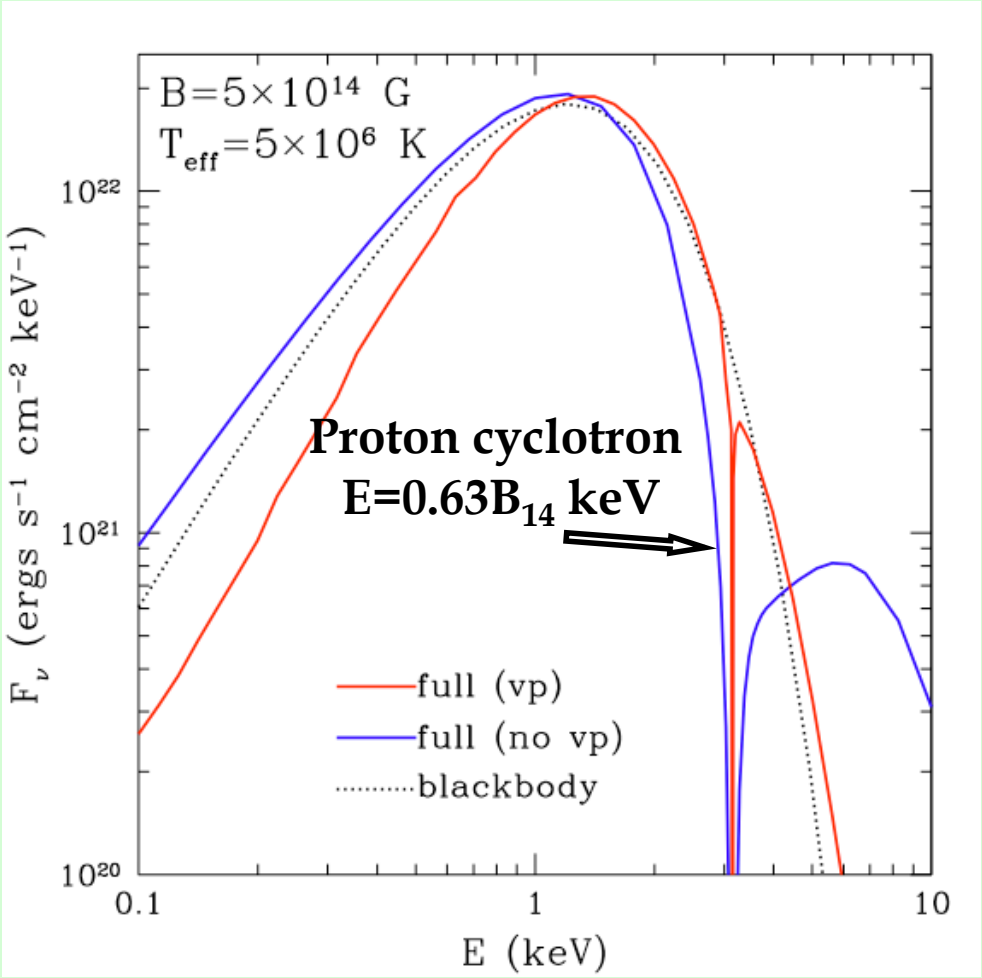

Lai et al. 2009

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Testing Quantum Gravity theories with X-ray polarimetry

Quantum Gravity should be effective on the Planck Energy scale ($E_{QG}=10^{19}$ GeV). But the proposed existence of space-time foam can produce detectable effects on radiation propagating on very long distance scales.

One of the major approach to quantization of Gravity is the Loop QG that predicts birefringence effects related to Lorentz Invariance Violation,

The result is a difference of light velocity for the two states of circular polarization:

$$V_+ = c\,[1+c(E/E_{QG})^n] \qquad V_- = c\,[1-c(E/E_{QG})^n]$$

→ The plane of linear polarization is subject to a rotation along the path

Testing Quantum Gravity theories with X-ray polarimetry

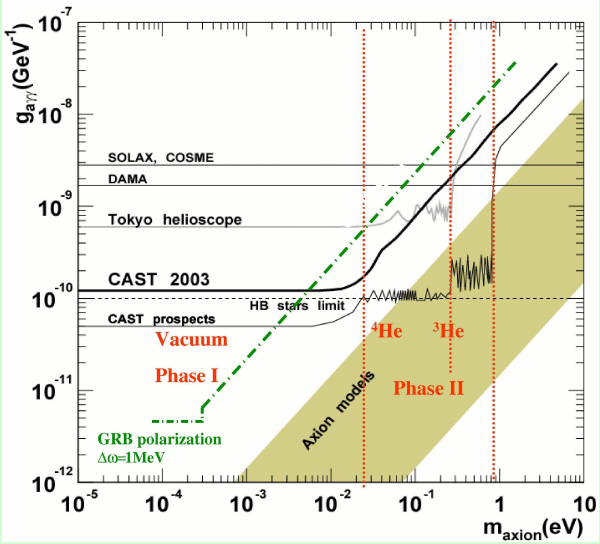
The rotation of the polarization angle is given by:

$$\Delta \phi(E) = \eta\ (D/hc)\ E^2/\ E_{QG} \approx 10^4\ \eta\ D\ (E/0.1\ MeV)^2$$

η is already constrained to be less than 10^{-9} (Maccione et al. 2008) by using the recent hard X-ray polarization measurement of the Crab with INTEGRAL (Dean et al. 2008).

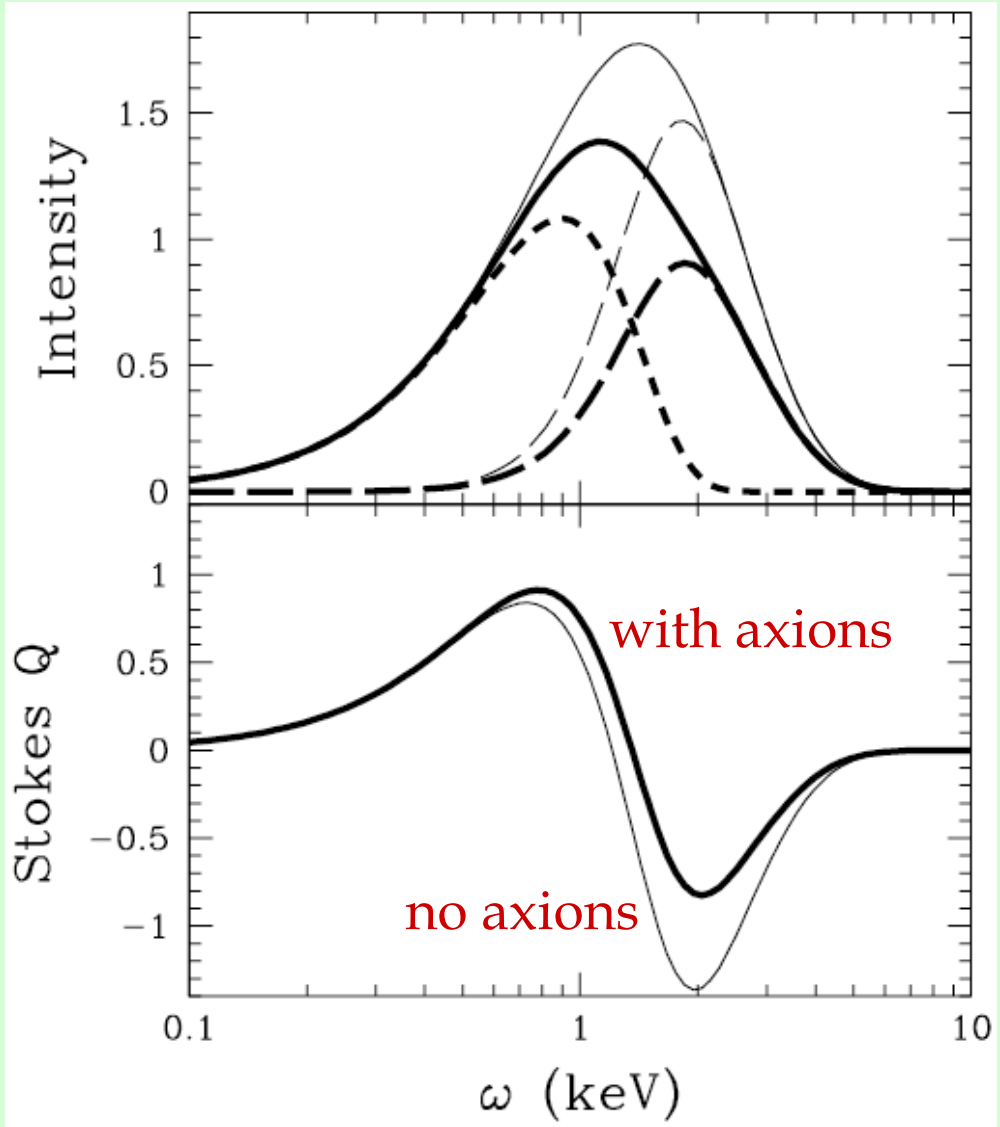
Extensive use of distant Blazars with IXO will confirm it and further enhance the precision of this measurement.

Search for axions



In the atmosphere of highly magnetized NS, photons (//-polarization component) can convert into axions (which are dark matter candidates)

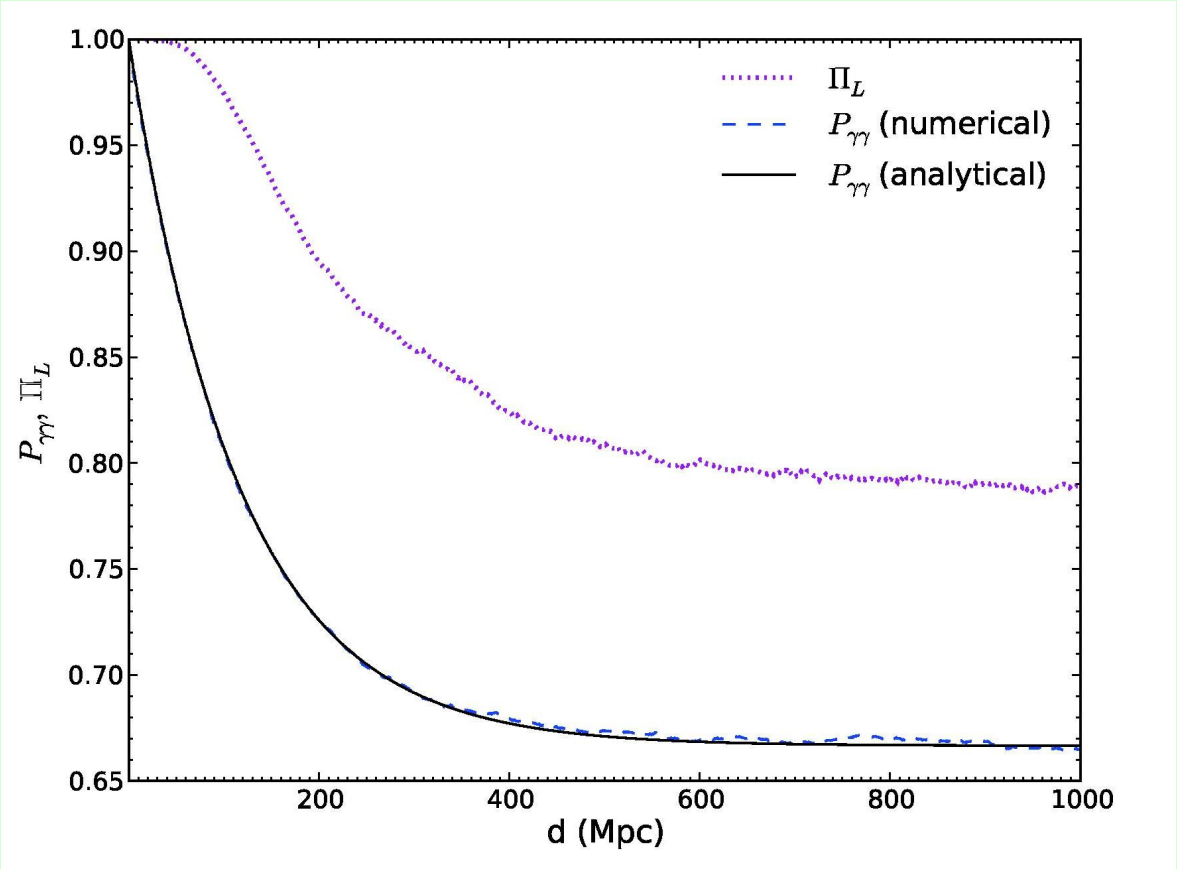
➔ **modify radiation spectra and polarization signals**



Lai & Heyl (2006)

Search for axions

Polarization properties are also modified by photon-axion coupling occurring in the small intergalactic field, when integrating over large distances (Bassan et al. 2010)



Summary

X-ray polarimetry is an important, when not unique, probe of strong gravity and extreme magnetic field effects.

It may also provide tests of fundamental physics (quantum gravity effects, axions, …)

Pathfinders like GEMS and NHXM will (re)-open the polarimetric window to the X-ray Universe, but IXO is required to fully exploit this technique